SHORT COMMUNICATION

PREDICTING AEOLIAN SAND TRANSPORT: REVISITING THE WHITE MODEL

STEVEN NAMIKAS* AND DOUGLAS J. SHERMAN

Department of Geography, University of Southern California, Los Angeles, CA 90089-0255, USA

Received 25 June 1996; Revised 25 October 1996; Accepted 11 December 1996

ABSTRACT

The derivation and history of the frequently cited aeolian transport model of White are considered in light of the continued replication of an error in the original expression. The error may have escaped notice because the expression is still dimensionally correct and it yields predictions that appear reasonable in comparison with both the predictions of other models and with field data. The incorrect expression has come to be identified as a distinct model. However, the correct formulation of the 'White model' is, in fact, a rearrangement of the Kawamura model with a slightly smaller (*c*.6%) empirical coefficient. © 1997 by John Wiley & Sons, Ltd.

Earth surf. processes landf., **22,** 601–604 (1997)
No. of figures: 1 No. of tables: 0 No. of refs: 21
KEY WORDS: aeolian sand transport; sediment transport models

INTRODUCTION

The purpose of this paper is to consider the ambiguous history and use of the White (1979) aeolian transport rate model. This model has been used in field studies and computer simulations, and cited extensively as exemplifying various aspects of transport process. One of the most comprehensive evaluations of aeolian transport models (Sarre, 1988) found that the White model provided the best fit to field measurements, especially at shear velocities in excess of $0{\cdot}28\,\mathrm{m\,s^{-1}}$. This finding supported use of the model in a subsequent study as the basis for estimating potential sand transport rates in a coastal dune system (Sarre, 1989). The White model has been incorporated into numerical simulations of the saltation process (Anderson and Hallet, 1986), and used as the basis for a computer simulation of beach–dune interaction (Sherman and Lyons, 1994). It has been cited as validating the transport rate to be an inverse function of the gravitational acceleration (Ungar and Haff, 1987), and as support for the position that there is a mass flux dependence on u_*^3 (Werner, 1990; Anderson and Haff, 1991). It has also been included in recent textbooks on aeolian geomorphology (Pye and Tsoar, 1990; Lancaster, 1995).

The White model is singled out here for two reasons. Unfortunately, the original publication included a version that contains a typographical error, and the erroneous version is still being employed and replicated in the literature some 16 years later. Second, although the 'White model' has come to be identified in the literature as a discrete entity, the correct formulation is a rearrangement of the earlier model proposed by Kawamura (1951).

BACKGROUND

The purpose of White's (1979) investigation was to compare the potential aeolian transport systems of Mars and Earth. As one of the theoretical bases for the research, it was presumed that transport rates on Earth could be adequately represented by the Kawamura (1951) model:

$$q = K\rho r/g(u_* - u_{*t})(u_* + u_{*t})^2 \tag{1}$$

* Correspondence to: S. Namikas

CCC 0197-9337/97/060601–04 $17.50 © 1997 by John Wiley & Sons, Ltd.

where q is the sediment transport rate, K is a dimensionless constant (2·78 from Kawamura's wind tunnel experiments), ρ is air density, g is gravitational acceleration, u_* is shear velocity, and u_{*_t} is the fluid threshold shear velocity. Earlier research had shown that threshold shear velocities on Mars could not be modelled accurately by standard terrestrial approaches (e.g. Bagnold, 1941). However, White was able to compare potential transport rates on the two planets by restricting consideration to the case of equivalent u_{*_t}/u_* ratios. White (1979) provided both a derivation of the Kawamura model (White's equations 11–19) and the model itself (White's equation 19). Presumably because of the focus on equivalent u_{*_t}/u_* ratios, the expression was then recast in the following form (White's equation 22):

$$q = 2{\cdot}61\,\rho/g u_*^3\,(1 - u_{*_t}/u_*)(1 + u_{*_t}^2/u_*^2) \tag{2}$$

where 2·61 is the empirical constant (K) derived from his laboratory results. White concluded that Equation 2 should be applicable on either Earth or Mars, and that ''This must be considered the main contribution of the present work'' (White, 1979, p. 4649).

Equation 2 is incorrect, however. The correct form is obtained by reversing the signs within the brackets, or by moving the exponent outside the bracket, giving:

$$q = 2{\cdot}61\,\rho/g u_*^3\,(1 - u_{*_t}/u_*)(1 + u_{*_t}/u_*)^2 \tag{3}$$

That the error in Equation 2 was typographical, rather than mathematical or conceptual, is supported by White's (1979) correct usage (in a rearranged form) in his abstract and in his figure 9. Surprisingly, this error apparently escaped the notice in the literature for nearly 15 years until Blumberg and Greeley (1993) published a correction in the form of Equation 3. The persistence of this problem is further evident in that typographical errors appear in two other published corrections of the White model, those in Blumberg (1993, equation 3.2) and Greeley *et al*. (1996, equation 4).

All three of the publications containing corrections specify that the new equation is a correction to the White (1979) model. Note that the term $(u_* - u_{*_t})(u_* + u_{*_t})^2$ from the Kawamura model (Equation 1, above), can be rewritten as $[u_*(1 - u_{*_t}/u_*][u_*(1 + u_{*_t}/u_*)]^2$ and simplified to the $u_*^3(1 - u_{*_t}/u_*)(1 + u_{*_t}/u_*)^2$ given by Blumberg and Greeley (1993) for the corrected 'White model'. The only difference between the Kawamura and corrected White equations, therefore, is that White's experimental data yielded a value of 2·61 for K instead of the 2·78 found by Kawamura. This results in a difference of only 6% in predicted transport rates. Given that larger differences in K have been reported elsewhere (e.g. Horikawa *et al*. (1983) found $K = 1{\cdot}0$), this revision seems insufficient to warrant the designation of White's equation as a distinct entity. As White (1979) pointed out, the fundamental contribution of that paper was to show that the (Kawamura) transport model was applicable on Mars as well as on Earth. No claim was made regarding development of a fundamentally new approach to modelling aeolian transport rates. Indeed, a subsequent paper (White, 1985) presents only Kawamura's (1951) form of the mass flux model.

DISCUSSION

It is not uncommon for errors to appear in the literature, typographical or otherwise. One recent textbook has typographical errors in the Bagnold, Kawamura, Lettau and Lettau, and White equations (Lancaster, 1995). There are also, but less frequently, conceptual errors, such as those associated with the Hardisty and Whitehouse (1988) slope correction model (Whitehouse, pers. comm.). In the present case, it is unusual that the error remained undetected (or unpublicized) for such a long time given the amount of attention paid to this model. Further, it is unusual for published corrections to be so variable, and for there to have been a general failure (apparently) to appreciate that the White model is simply a rearrangement of the expression developed by Kawamura.

Reasons for this may stem from several sources. First, Equation 2 'looks' appropriate. The equation is dimensionally correct, contains familiar and expected terms, and is based upon a well-established foundation – the Kawamura model. Further, the incorrect (Equation 2) and correct (Equation 3) versions are visually quite

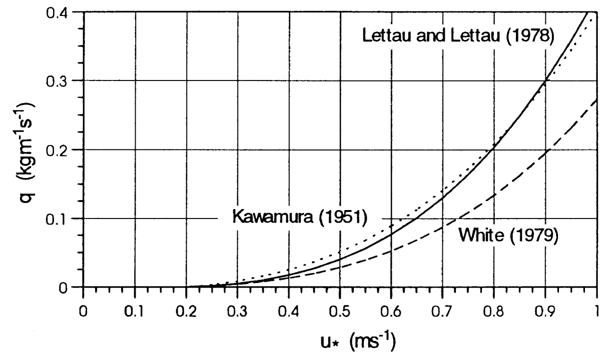

Figure 1. Transport rates for 0·2 mm sand predicted by the Kawamura (1951), Lettau and Lettau (1978) and White (1979) models. Note that the incorrect version of the White model (Equation 2 in text) is used for the figure.

similar. Second, Equation 2 yields smaller predicted transport rates relative to those obtained from other models that incorporate an explicit threshold shear velocity term. Figure 1 illustrates transport rates for 0·2 mm sands, as predicted by the Kawamura (1951), Lettau and Lettau (1978) and incorrect White (1979) equations. At shear velocities greater than about 0·40 m s^{-1}, the White model yields the smallest transport rate. It is common for field measurements of sand transport rates to be less than predictions derived from local data and standard transport rate models (e.g. Sherman, 1990; Bauer *et al.*, 1990). Therefore predictions made with White's equation may conform more closely with field measurements, reinforcing the perception that the model is formulated correctly. Considering the effort expended on attempts to explicate aeolian transport, it is both frustrating and humbling that a mistaken expression appears to be as successful at predicting field transport rates as any of the painstakingly developed theoretical constructs currently available. Finally, the primary reason that such errors propagate in the literature is that we fail to read carefully and check derivations conscientiously. Time is precious, and demands upon it are many. The fault is ours.

ACKNOWLEDGEMENT

We would like to thank B. O. Bauer and two anonymous reviewers for helpful comments on this manuscript.

REFERENCES

Anderson, R. S. and Haff, P. K. 1991. 'Wind modification and bed response during saltation of sand in air', *Acta Mechanica*, Supplement **1**, 21–51.

Anderson, R. S. and Hallet, B. 1986. 'Sediment transport by wind: toward a general model', *Geological Society of America Bulletin*, **97**, 523–535.

Bagnold, R. A. 1941. *The Physics of Blown Sand and Desert Dunes*, Chapman and Hall, London, 256 pp.

Bauer, B. O., Sherman, D. J., Nordstrom, K. F. and Gares, P. A. 1990. 'Aeolian transport measurement across a beach and dune at Castroville, California', in Nordstrom, K. F., Psuty, N. and Carter, B. (Eds), *Coastal Dunes: Form and Process*, Wiley, New York, 39–56.

Blumberg, D. G. 1993. *Prediction of Aeolian Processes by Remote Sensing and Models*, Unpublished PhD dissertation, Department of Geology, Arizona State University, Tempe.

Blumberg, D. G. and Greeley, R. 1993. 'Field studies of aerodynamic roughness length', *Journal of Arid Environments*, **25**, 39–48.

Greeley, R., Blumberg, D. G. and Williams, S. H. 1996. 'Field measurements of the flux and speed of wind-blown sand', *Sedimentology*, **43**, 41–52.

Hardisty, J. and Whitehouse, K. J. S. 1988. 'Evidence for a new sand transport process from experiments on Saharan dunes', *Nature*, **332**, 532–534.

Horikawa, K., Hotta, S., Kubota, S. and Katori, S. 1983. 'On the sand transport rate by wind on a beach', *Coastal Engineering in Japan*, **26**, 100–120.

Kawamura, R. 1951. *Study of Sand Movement by Wind*, Hydraulic Engineering Laboratory Report HEL-2-8, University of California, Berkeley, 57 pp. (Translated 1964).

Lancaster, N. 1995. *Geomorphology of Desert Dunes*, Routledge, New York, 257 pp.

Lettau, K. and Lettau, H. 1978. ‘Experimental and micrometeorological field studies of dune migration’, in Lettau, K. and Lettau, H. (Eds), *Exploring the World’s Driest Climate*, Report No. 101, Institute for Environmental Studies, University of Wisconsin, Madison, 110–147.

Pye, K. and Tsoar, H. 1990. *Aeolian Sand and Sand Dunes*, Unwin-Hyman, London, 342 pp.

Sarre, R. D. 1988. ‘An evaluation of aeolian sand transport equations using intertidal zone measurements, Saunton Sands, England’, *Sedimentology*, **35**, 671–679.

Sarre, R. D. 1989. ‘Aeolian sand drift from the intertidal zone on a temperate beach: potential and actual rates’, *Earth Surface Processes and Landforms*, **14**, 247–258.

Sherman, D. J. 1990. ‘A method for measuring aeolian sediment transport rate’, in Davidson-Arnott, R. W. G. (Ed.), *Proceedings of the Symposium on Coastal Sand Dunes*, National Research Council of Canada, Ottawa, 37–47.

Sherman, D. J. and Lyons, W. 1994. ‘Beach-state controls on aeolian sand delivery to coastal dunes’, *Physical Geography*, **15**, 381–395.

Ungar, J. E. and Haff, P. K. 1987. ‘Steady state saltation in air’, *Sedimentology*, **34**, 289–299.

Werner, B. T. 1990. ‘A steady-state model of wind-blown sand transport’, *Journal of Geology*, **98**, 1–17.

White, B. R. 1979. ‘Soil transport by winds on Mars’, *Journal of Geophysical Research*, **84**, 4643–4651.

White, B. R. 1985. ‘The dynamics of particle motion in saltation’, in Barndorff-Nielsen, O. E., Moller, J. T., Rasmussen, K. and Willetts, B. B. (Eds), *Proceedings of the International Workshop on the Physics of Blown Sand*, Memoir No. 8, Department of Theoretical Statistics, University of Aarhus, Denmark, 101–140.